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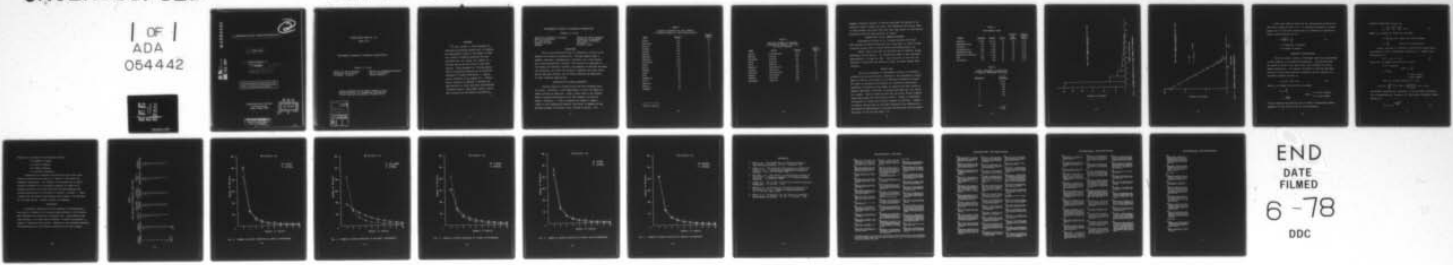
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10 Russell C. Coile

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MARCH 1978

BIBLIOMETRIC STUDIES OF SCIENTIFIC PRODUCTIVITY

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ABSTRACT

In 1926, Alfred J. Lotka examined the scientific publishing productivity of chemists. His bibliometric study of the number of chemists listed in Chemical Abstracts who had published one, two, three, etc. papers in a ten-year period was the first of many such studies. Lotka proposed an inverse square law of scientific productivity in which the frequency of authors publishing  $x$  papers varied inversely as the square of  $x$ . Bibliometric research is underway to explore the applicability of other frequency distributions including Fisher's logarithmic series, Yule's Beta function and the Weibull distribution.

## BIBLIOMETRIC STUDIES OF SCIENTIFIC PRODUCTIVITY

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### BACKGROUND

One of the interesting areas in information science is the question of scientific productivity. How many papers might a chemist, physicist, mathematician, biologist, etc. write during his or her professional lifetime? This question is pertinent to the editors of technical journals, the managers of abstract services, the librarians who work with journals, abstracts and other information retrieval systems, and to fellow chemists and physicists in their research laboratories.

### PRODUCTIVITY OF GREAT SCIENTISTS

Various studies of productivity have been conducted over the years. Initially, it was fashionable to count the number of papers written by great men. Table 1 shows some of the achievements of eminent scientists of the 19th century, as given by Dennis, reference 1. Table 2 presents the number of papers listed in the Biographical Memoirs (1943-1952) of members of the National Academy of Sciences, also as given by Dennis. For

TABLE 1  
 EMINENT SCIENTISTS OF 19th CENTURY  
 (30 Years Assumed for Publishing Period)

<u>Name</u>	<u>Papers</u>	<u>Papers/ Year</u>
Liebig	307	10
Bertholet	236	8
Pasteur	172	6
Faraday	161	5
Poisson	158	5
Aggasiz	153	5
Herschel	151	5
Humboldt	142	5
Gay-Lussac	134	4
Gauss	123	4
Kelvin	114	4
Maxwell	90	3
Joule	89	3
Davy	86	3
Helmholtz	86	3
Lyell	76	3
Hamilton	71	2
Darwin	61	2
Riemann <sup>1</sup>	19	1

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<sup>1</sup>Died at age 40.

TABLE 2

NATIONAL ACADEMY OF SCIENCES  
BIOGRAPHICAL MEMOIRS 1943-1952  
(40 Years Assumed)

<u>Name</u>	<u>Field</u>	<u>Papers</u>	<u>Papers/ Year</u>
Levene	Biochemistry	768	19
Merriam	Zoology	626	16
Stegneger	Zoology	499	12
Davis	Geology	477	12
Barus	Physics	420	11
Kennelly	Engineering	362	9
Johnson	Chemistry	358	9
Hrdlicka	Anthropology	340	9
Campell	Astronomy	330	8
Cushing	Medicine	306	8
Davenport	Genetics	303	8

example, Professor Kennelly of Harvard published 362 papers for an average of about 9 papers per year. The assumption was usually made in these studies that there must have been some papers of high quality associated with this high quantity of output.

#### PRODUCTIVITY OF MR. AVERAGE SCIENTIST

Bibliometric studies of Mr. Average Scientist have used such sources as Chemical Abstracts for a data base, or lists of publications written over a 25-year period by mathematicians, etc.

Table 3 shows some data for publications of chemists, mathematicians, and biologists. Mr. Average Man seems to have published approximately 0.1 paper per year. Also this data is only for the fraction of scientists who publish at least one paper during their lifetime.

#### LOTKA'S LAW

One of the pioneers in bibliometric studies of scientific productivity was Alfred Lotka, reference 2, who published a classic paper in 1926 in the Journal of the Washington Academy of Science. His paper on frequency distributions of scientific productivity presented an analysis of the number of chemists who were listed in Chemical Abstracts, 1907-1916, as having published one, two, three, etc. papers. Table 4 shows his data for the senior author chemists whose names began with the letters A and B. Figure 1 illustrates the percent of authors with various numbers of abstracts. Figure 2 is Lotka's log-log plot of this data showing, for the chemists who published, how approximately 57 percent had published only one paper. The slope of the line was about -1.9.

TABLE 3  
BIBLIOMETRIC DATA

<u>Field</u>	<u>Authors</u>	<u>Papers</u>	<u>Years</u>	<u>Percent One Paper</u>	<u>Papers/ Author/ Year</u>
Chemists	6,891	22,939	10	58	0.33
Mathematicians	278	1,124	25	48	0.16
Fluidics	401	529	9	69	0.15
Drosophilists	826	3,662	33	51	0.13
Econometricians	721	1,759	20	60	0.12
Operations Research	783	1,158	15	76	0.10
ACM	420	383	10	83	0.09
Biologists	130	264	28	59	0.07

TABLE 4  
LOTKA'S FREQUENCY DISTRIBUTION  
OF CHEMICAL ABSTRACTS 1907-1916

<u>Abstracts</u>	<u>A &amp; B Chemists</u>
1	3,991
2	1,059
3	493
4	287
5	184
6	131
'	
'	
'	
346	<u>1</u> 6,891

DATA FROM CHEMICAL ABSTRACTS 1907-1916

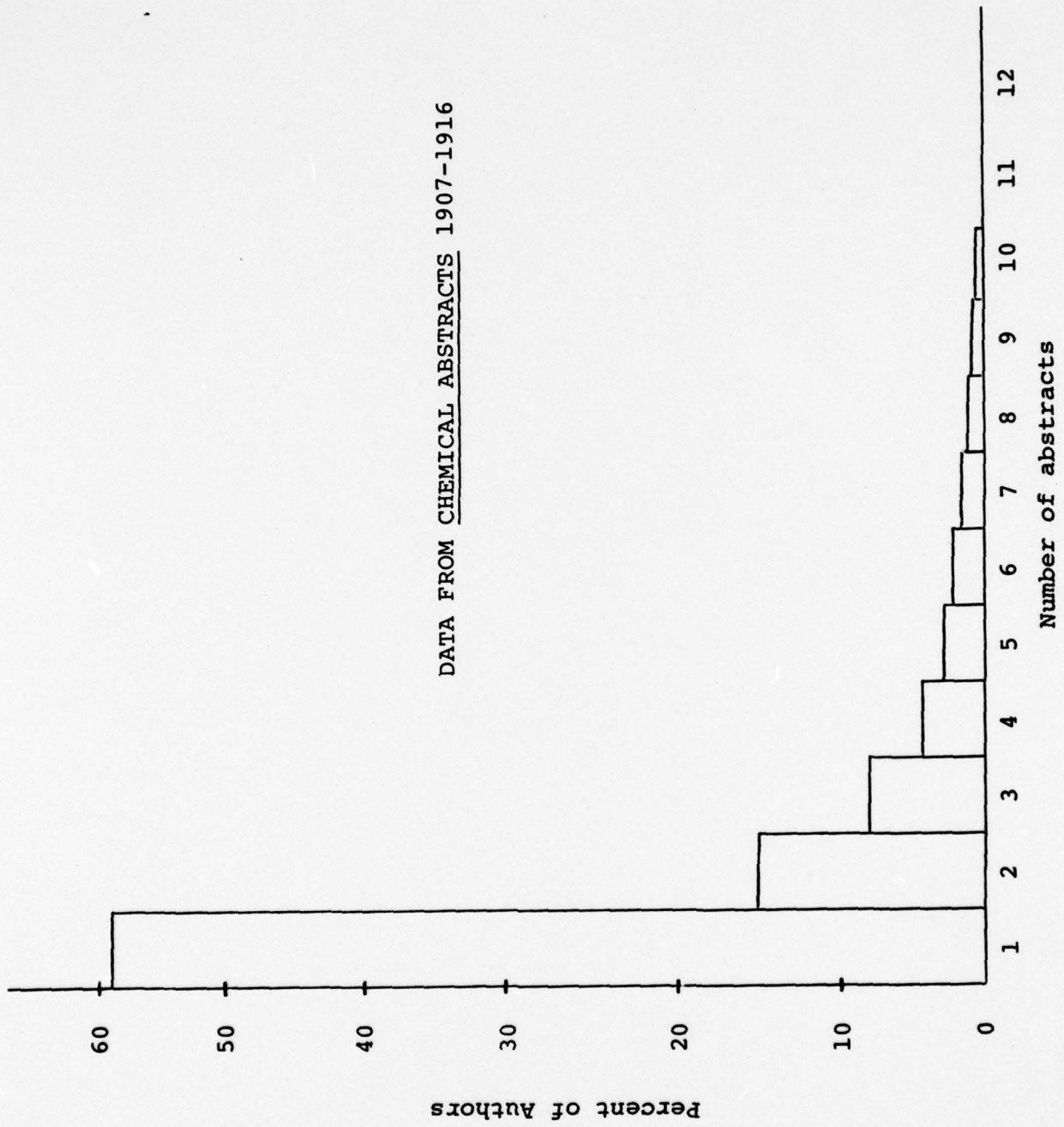


FIG 1: PERCENT AUTHORS WITH A GIVEN NUMBER OF ABSTRACTS

DATA FROM CHEMICAL ABSTRACTS 1907-1916

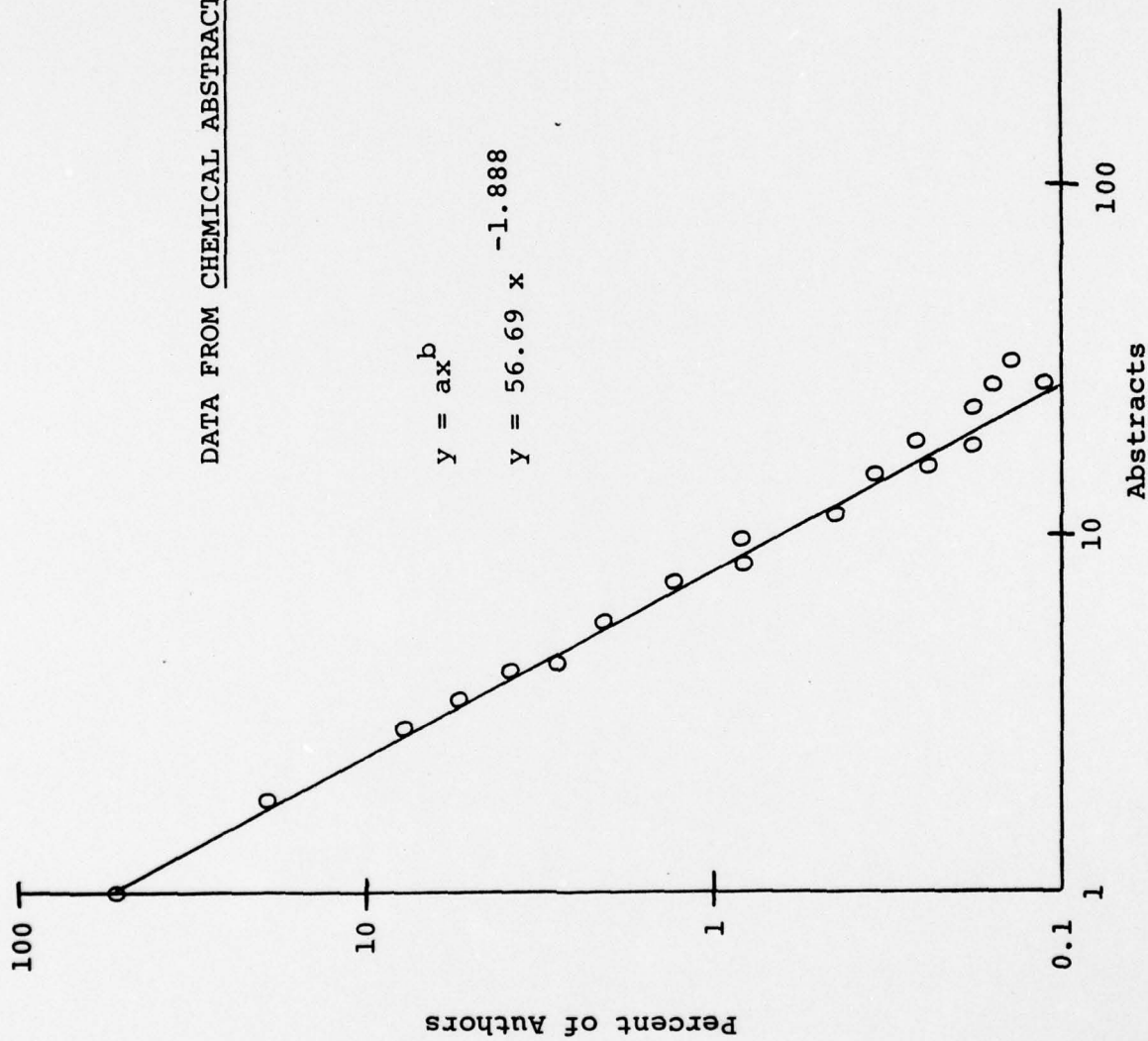


FIG. 2: PERCENT AUTHORS VERSUS ABSTRACTS

Lotka then examined some data for publications of physicists and found a slope of about -2.0. He therefore proposed an inverse square law of scientific productivity for chemists and physicists. Lotka's Inverse Square Law is:

$$y = \left( \frac{600}{\pi^2} \right) \frac{1}{x^2} \quad (1)$$

y is Frequency of Authors

x is Number of Papers.

#### FREQUENCY DISTRIBUTIONS

There have been a number of different theoretical approaches to this question of frequency distributions. Some workers were not aware of Lotka's law, while other have attempted to find a better formulation. For example, Williams, in studying the publications of biologists, examined a geometric series, equation (2). Williams' Geometric Series is:

$$n_1, n_1x, n_1x^2, \text{ etc.} \quad (2)$$

Where  $n_1$  is number of authors of one paper,

$$n_1 = \frac{S^2}{N}$$

where S is total authors  
N is total papers.

$$x = \frac{(N-S)}{N}$$

He also explored the possible use of Fisher's logarithmic series, equation (3) and found a good fit for biologists.

Fisher's Logarithmic Series is:

$$n_1, \frac{n_1 x}{2}, \frac{n_1 x^2}{3}, \frac{n_1 x^3}{4}, \text{ etc.} \quad (3)$$

Where  $n_1$  is number of authors of one paper

$$S = \frac{n_1}{x} [-\ln(1-x)] \quad \text{where } S \text{ is total authors.}$$

$$N = \frac{n_1}{1-x} \quad \text{where } N \text{ is total papers.}$$

Simon, reference 4, proposed a Beta-function model which he called the "Yule" distribution, equation (4). Simon's Yule distribution is:

$$f(i) = A B(i, \rho+1) \quad (4)$$

Where  $f(i)$  is number of authors of  $i$  papers,

$A$  is a constant

$$\text{where } \alpha = \frac{S}{N}$$

$$\rho \text{ is } \frac{1}{1-\alpha}$$

$S$  total authors

$N$  total papers

$B(i, \rho+1)$  is Beta-function of  $i, \rho+1$ .

$$B(i, \rho+1) = \int_0^1 \lambda^{i-1} (1-\lambda)^\rho d\lambda = \frac{\Gamma(i)\Gamma(\rho+1)}{\Gamma(i+\rho+1)} \quad (0 < i, 0 < \rho < \infty)$$

The Weibull distribution, reference 5, has also been considered for its applicability, equation (5). The Weibull Frequency Distribution is:

$$F(x) = 1 - e^{-\frac{(x-C)^B}{A}} \quad (5)$$

Where  $F(x)$  is Cumulative Distribution Function

X is Number of Papers

A is Scale Parameter

B is Shape Parameter

C is Location Parameter.

Predictions of frequency distributions using these theoretical models have been made for a number of data bases for different disciplines. For example, the distribution of publications (reference 6) of biologists studying the genetics of *Drosophila* during the period 1905-1938 has been compared with various predictions as illustrated in Figures 3 through 7. Table 5 shows that the Weibull distribution would appear to be the best fit of those tested. Further research is underway.

#### CONCLUSION

Preliminary examination of the problem of forecasting how many papers a chemist or a biologist might publish in his lifetime has indicated wide variations in productivity. Many chemists may never publish. For those who do publish, it should be possible to predict a frequency distribution. Research is now underway exploring the applicability of the Weibull distribution for this purpose.

TABLE 5

## PUBLICATIONS ON DROSOPHILA (1905-1938)

<u>Number of Papers</u>	<u>Number of Authors</u>	<u>Lotka's Law</u>	<u>Williams' Geometric Series</u>	<u>Fisher's Logarithmic Series</u>	<u>Simon's Yule Distribution</u>	<u>Weibull Distribution</u>
1	418	502	186	305	466	417
2	126	126	144	140	141	132
3	69	56	112	85	66	65
4	44	31	87	59	37	41
5	27	20	67	43	24	29
6	26	14	52	33	16	21
7	13	10	40	26	12	17
8	14	8	31	21	9	13
9	10	6	24	17	7	11
10	8	5	19	14	6	9
11 or more	71					
	<u>826</u>					

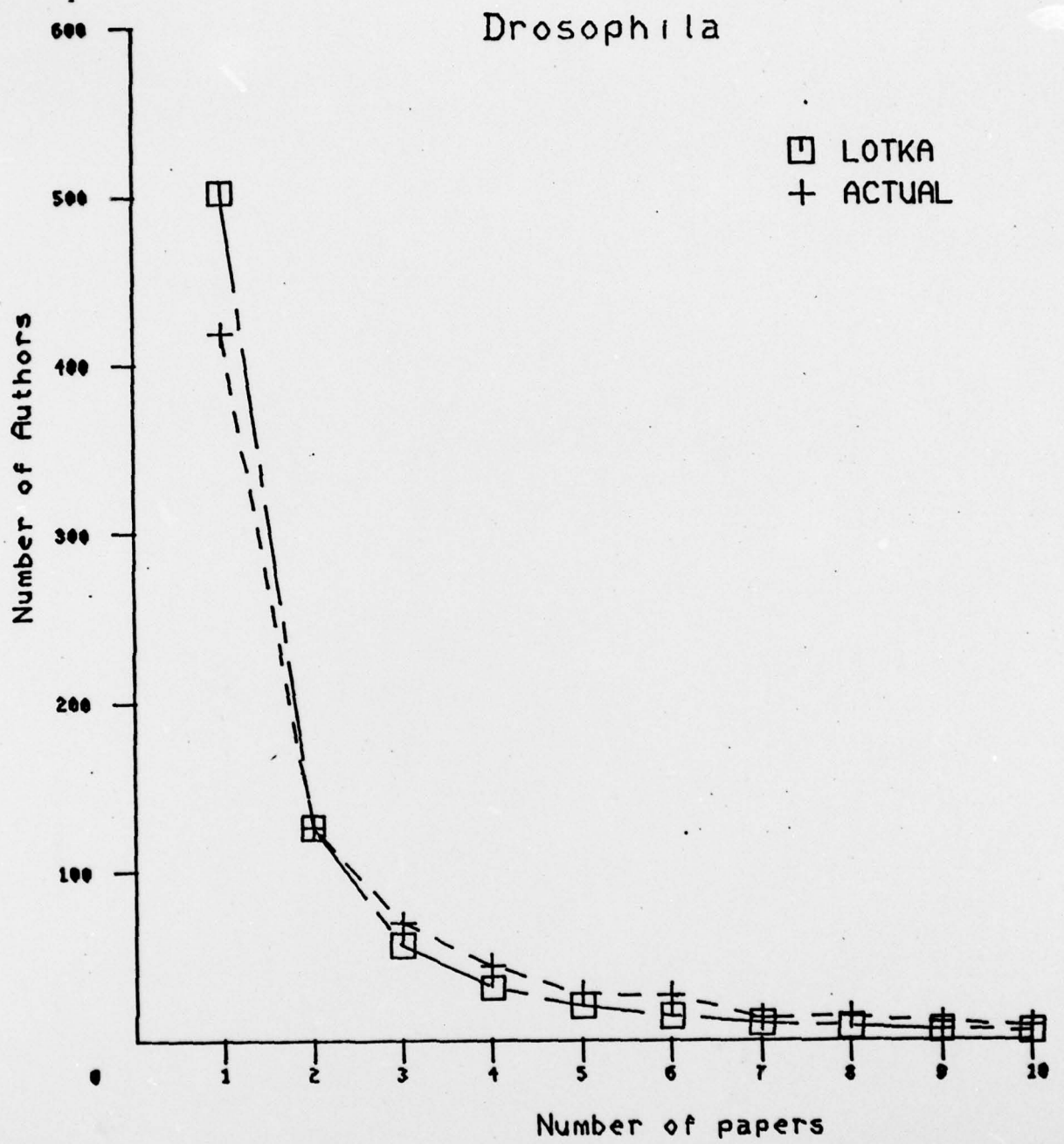


FIG. 3: NUMBER OF AUTHORS PREDICTED BY LOTKA'S DISTRIBUTION

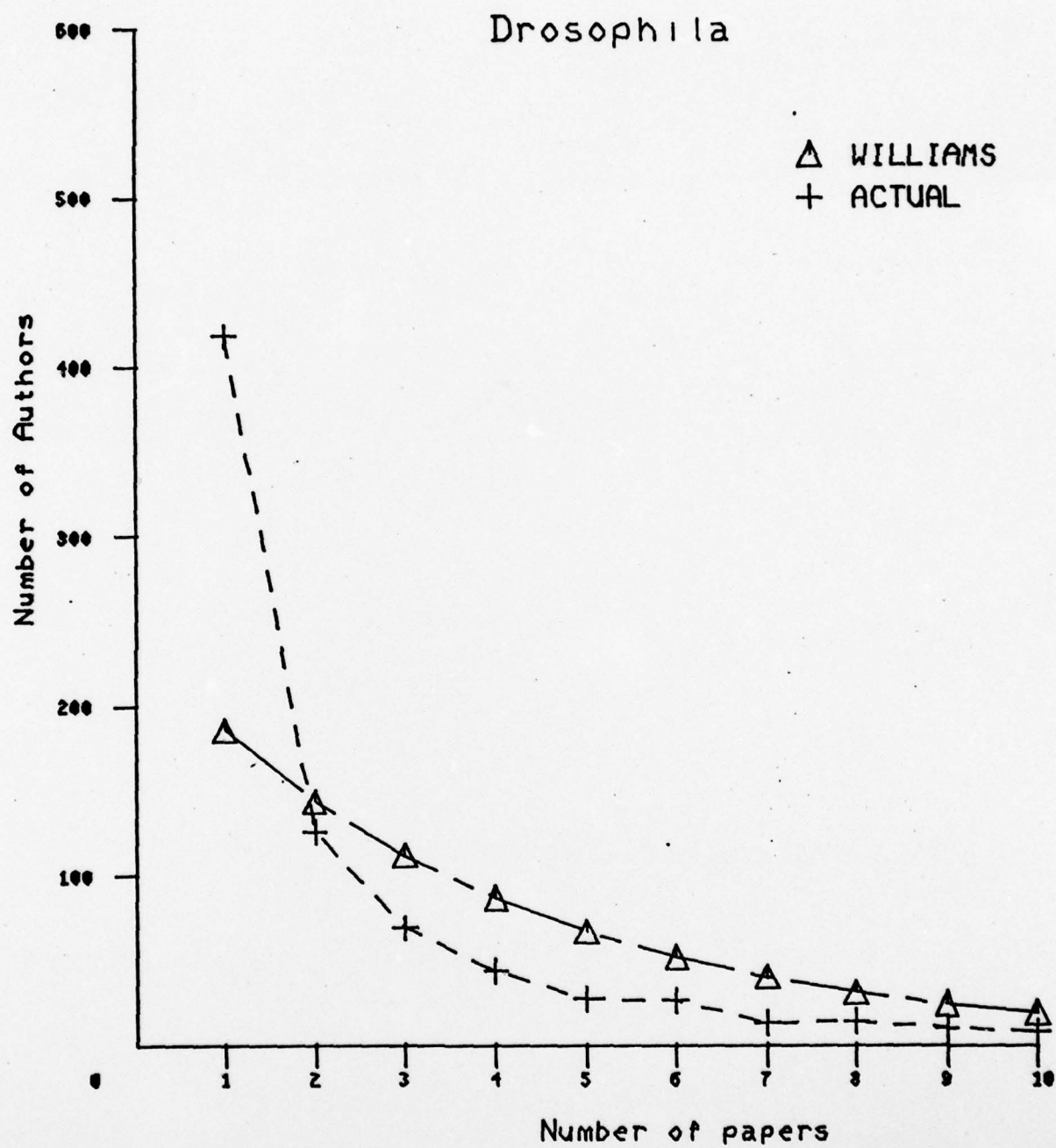


FIG. 4: NUMBER OF AUTHORS PREDICTED BY WILLIAMS' DISTRIBUTION

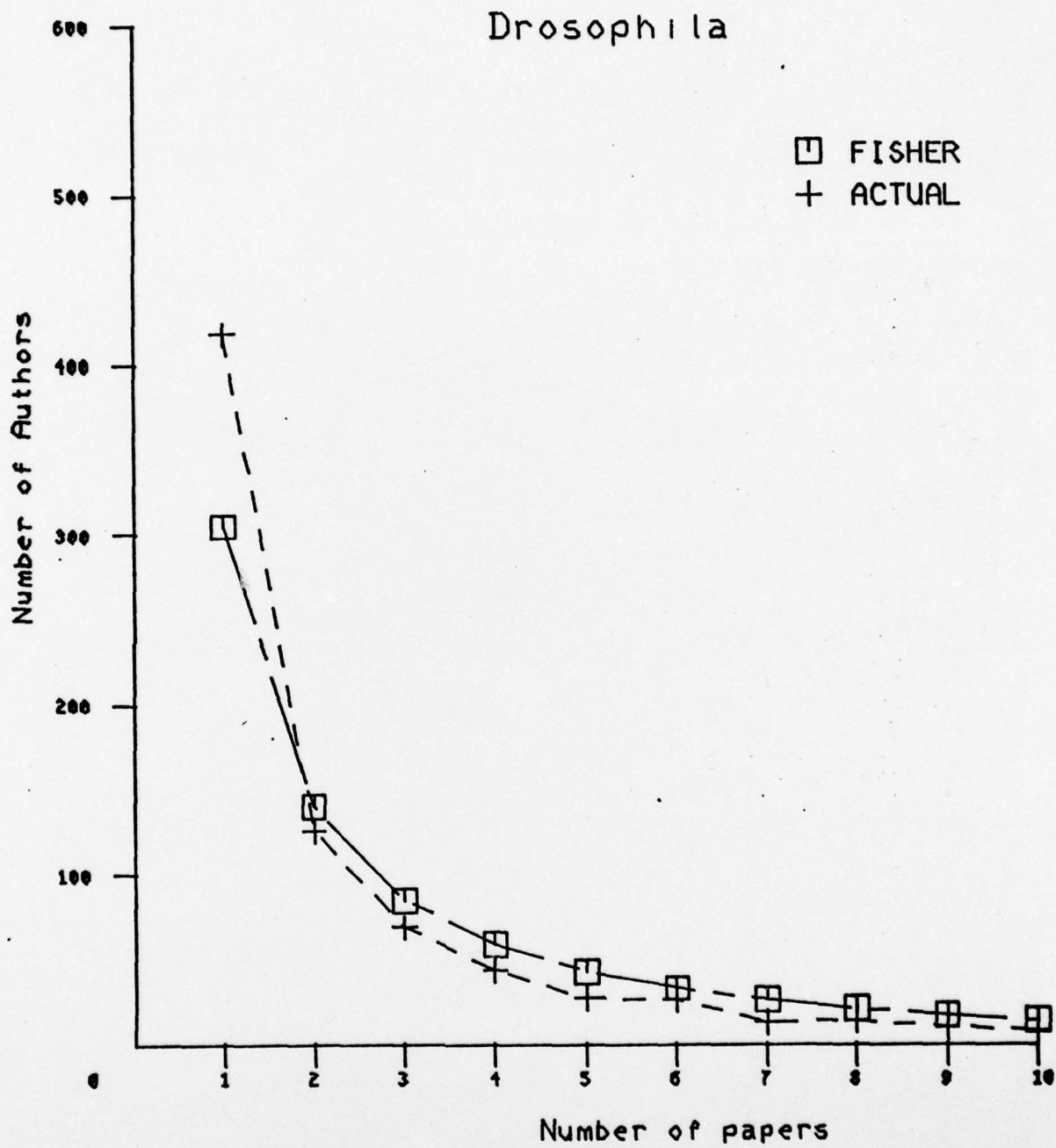


FIG. 5: NUMBER OF AUTHORS PREDICTED BY FISHER'S DISTRIBUTION

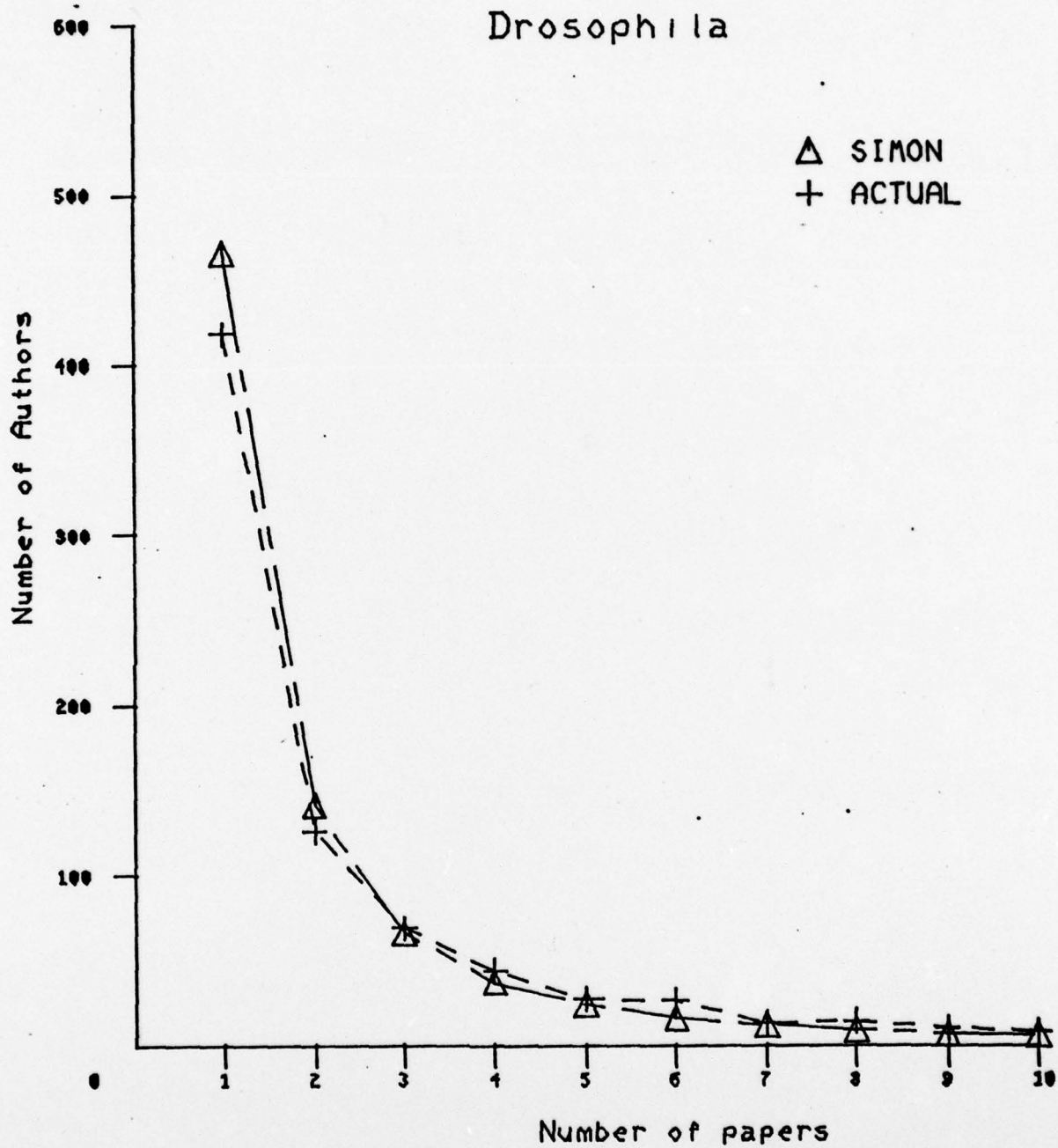


FIG. 6: NUMBER OF AUTHORS PREDICTED BY SIMON'S YULE DISTRIBUTION

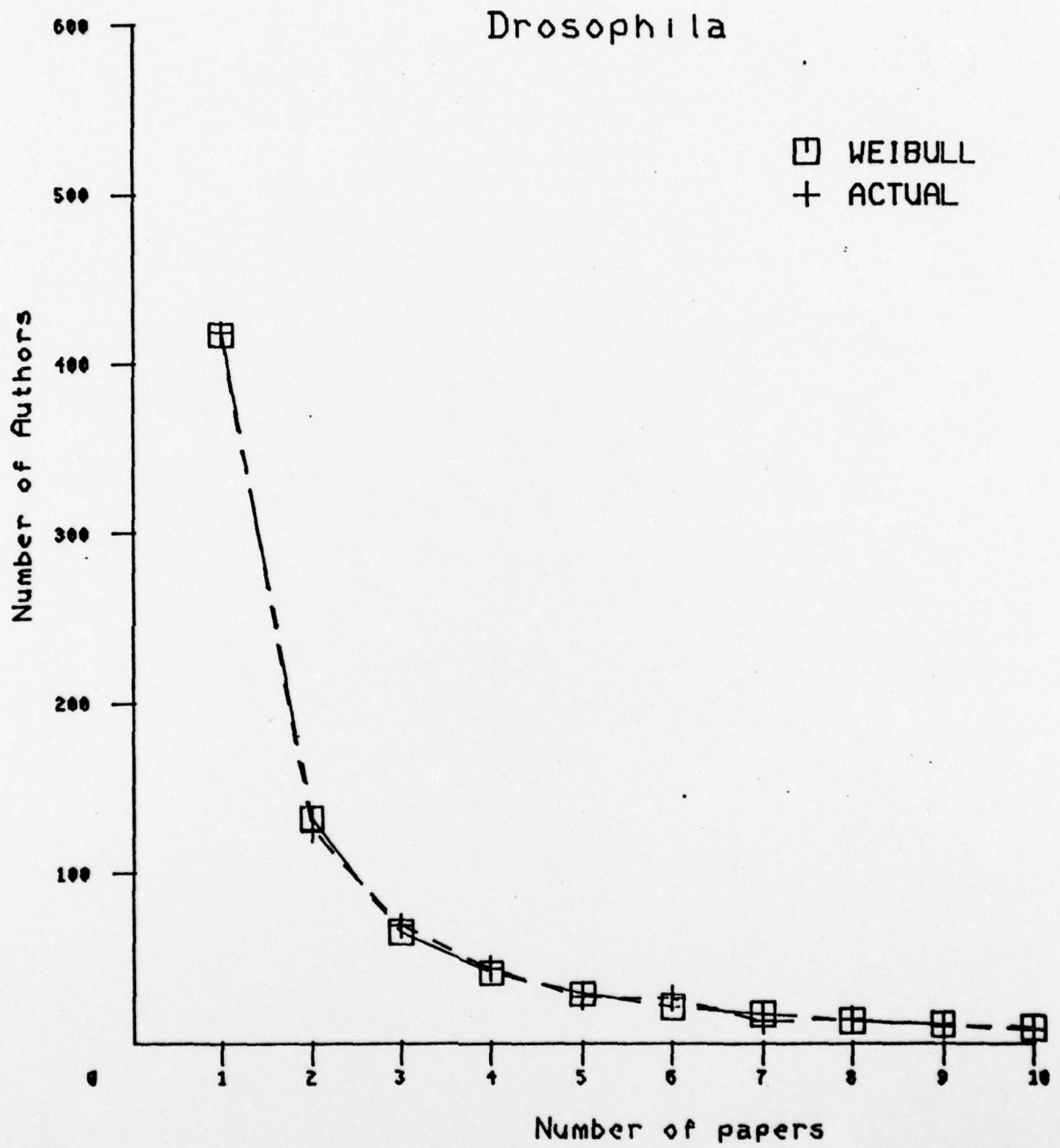


FIG. 7: NUMBER OF AUTHORS PREDICTED BY WEIBULL DISTRIBUTION

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